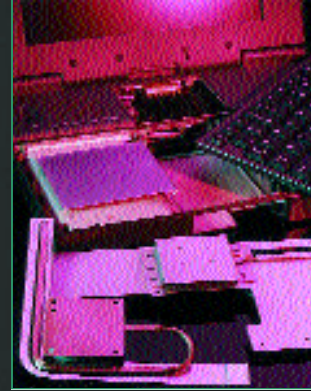
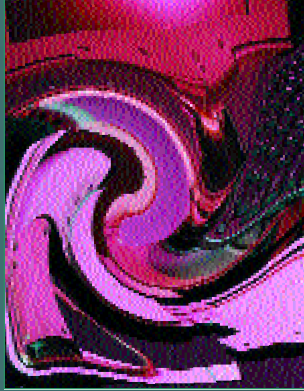


## COMPUTER HARDWARE AND SOFTWARE



Computer hardware and software have become an essential part of America's way of doing business. For example, corporate presentations are now routinely developed on personal computers and recorded on data storage drives, and proprietary information on company networks is protected from hackers and hostile insiders by information security software. Many types of advanced technology, such as electronics and optics, can improve the speed of computers and capacity of data storage drives. New software technology can also protect computer networks against industrial spies accessing company information from the Internet.

### Today's Market

Millions of personal computers (PCs) are reaching international markets. PC shipments surged 25 percent worldwide in 1995 from the previous year, with over 59 million units shipped. In the United States, PC shipments increased by a rate of 21 percent from the 1994 level.<sup>1</sup> Software is becoming a hot industry, too, with more than 8,000 companies developing software products. In 1996, the software industry's estimated total revenue reached well into the tens of billions of dollars; it is expected to grow at a rate of 27 percent.<sup>2</sup>

### Tomorrow's Opportunity

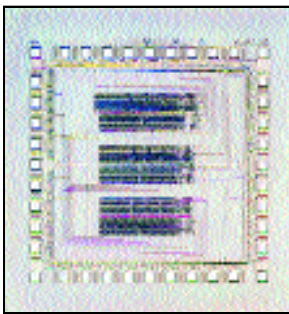
BMDO has funded technology for ballistic missile defense that can also provide the computer and software industries with innovative solutions to help the United States maintain a strong presence in these ever-growing world markets. Much of this technology covers such emerging areas as optics, electronics, neural networks, and information security. The following section describes six of these technologies.

<sup>1</sup>Carlton, Jim. 1996. PC shipments surged 25 percent worldwide in 1995. Computer News, 31 January. World Wide Web at <http://www.newstimes.com/archive/jan3196/cpa.htm>.

<sup>2</sup>Software Publishers Association. 1997. General issues: SPA to host congressional breakfast series. Washington Connections Monthly. January. World Wide Web at [http://www.spa.org/gvmnt/Wash2\\_0.htm#anchor1251453](http://www.spa.org/gvmnt/Wash2_0.htm#anchor1251453).

... a new and fundamentally more expressive "language" for designing digital electronics.

TO ACCELERATE PRODUCT  
DEVELOPMENT, THESEUS  
IS FORMING STRATEGIC  
ALLIANCES WITH  
MAJOR ELECTRONICS  
CORPORATIONS.



■ Pictured above is a layout of one of Theseus' prototype chips. It contains no detailed timing analysis.

## PARADIGM SHIFT IN DIGITAL CIRCUIT DESIGN ELIMINATES THE CLOCK

Widely accepted as the fundamental design paradigm in the computer industry today, Boolean logic has serious shortfalls in how it provides and moves information through digital circuits. Its circuit topology (the layout of transistors and their connection) is specifically designed for data processing, inherently preventing data movement from one processing step to the next. Therefore, "clocks" must regulate the movement of information packets.

Not only is this design approach inefficient (the need for and use of input and output data may not match a particular clock cycle), but clocks account for up to 50 percent of the design cost, up to 25 percent of the manufacturing cost, and 40 percent of the power consumed in operation. More important, clocks present a potentially intractable barrier to faster, denser chip design. Denser circuit designs place more features on a chip, making the design and distribution of clock signals increasingly difficult.

To overcome this problem, Theseus Research, Inc. (Minneapolis, MN), formed Theseus Logic, Inc. (St. Paul, MN), to develop a patented chip technology called NULL Convention Logic™ (NCL). Representing a fundamental paradigm shift in the computer industry, this technology eliminates the need for clocks, allowing faster, more efficient, and better integrated internal computer systems. Fully compatible with existing fabrication processes and with existing clocked systems, NCL yields clockless circuits and systems that are straightforward to design and easy to test. Multichip integration is essentially "plug and play" as chips in a system inherently coordinate themselves regardless of their varying throughput rates.

Supporting the company's business strategy of licensing NCL throughout the industry, Theseus recently signed a five-year deal with Sanders, a Lockheed Martin Company. This strategic alliance provides Theseus with an established partner that can help insert the technology into system applications. As part of this alliance, Sanders and Theseus have started working on a \$2.3 million Defense Advanced Research Projects Agency program, with an additional investment from Lockheed. The program aims to develop NCL-based Digital Signal Processors for system validation in the F-22 Advanced Tactical Fighter test bed.

In 1996, Theseus raised \$1.9 million in a private stock offering, and the company is preparing another stock offering in 1997 to augment ongoing development funding from government agencies and private corporations.

### ABOUT THE TECHNOLOGY

All-digital electronic operations are based on two data values, usually represented as binary mathematics employing the digits 0 and 1. NCL employs a third value, the null, which indicates that no input or output value is present. Using the null value, NCL circuits can perform binary data processing functions without needing a clock circuit to synchronize data inputs and outputs. Each combinatorial circuit inherently "knows" when it has completed processing a data set, when it is reset, and when it is ready to process another data set. All communication is local and asynchronous.

NCL allows high-performance asynchronous chips without any detailed timing analysis. In a BMDO SBIR project, Theseus developed seven proof-of-concept asynchronous chips. In tests, these chips "worked perfectly on the first pass" said Ken Wagner, president of Theseus Logic. Tests also showed that the chips can operate at extremely wide temperature and voltage levels. Theseus demonstrated that input supply voltage on NCL-based chips can be varied during run time from as low as 0.5 volts to over 9 volts, allowing smooth control of speed and power consumption.

## HIGH-DENSITY OPTICAL MEMORY RESULTS IN LICENSING AGREEMENTS

High-density data storage systems, essential to the survival of today's information-oriented companies, are some of the hottest items in the \$20 billion computer storage device market.<sup>1</sup> Magnetic floppy disks and optical compact discs temporarily meet some of this demand, but companies still search for higher density technologies to store the flood of data that drives their business processes.

Researchers at Oak Ridge National Laboratory (ORNL; Oak Ridge, TN) developed a high-density optical memory with about 100 times more storage capacity than previous technology. Called surface-enhanced Raman optical data storage (SERODS), this technology offers benefits for virtually any application requiring vast data storage, such as optical archive storage for libraries or insurance companies or data banks for financial institutions. Two companies are now commercializing the high-density optical memory through licensing agreements with ORNL and its operator, Lockheed Martin Corporation.

The first licensee, World Library, Inc., created a new company called SEROTECH, Inc., to develop compact disc read-only memory (CD-ROM) and read/write CD products based on SERODS. World Library specializes in publishing text-based, interactive CD-ROM products and expects SERODS to increase the storage capacity of its products by 1,500 percent. The second licensee, Photronix, Inc., also spun off a new company, called CDEX<sup>®</sup> Corporation, to market its future SERODS products, such as a rewritable CD-ROM called CDE<sup>®</sup>, a video cube, and a digital still camera with optical card.

Current CD-ROMs have a storage capacity of up to 600 megabytes (600 million bytes), or the equivalent of 270,000 pages of typewritten text. However, a 12-inch CD using SERODS technology contains roughly 100 times more storage. This capacity could store 18,000 sets of the Encyclopedia Britannica, the name of every taxpayer registered with the Internal Revenue Service, or all the records on a U.S. Navy ship. With further development, SERODS could store as much as 1,000 times more information than fits on today's disks.

BMDO originally funded SERODS research to develop an alternative technique for optically storing massive amounts of computer data. Although designed as write-once, read-many-times (WORM) technology, SERODS writes, reads, and deletes. Layered SERODS disks could allow 3-D data storage. This unique feature would permit simultaneous scanning of multiple tracks or layers, leading to improved data transfer rates.

### ABOUT THE TECHNOLOGY

SERODS is based on the principle that the surface-enhanced Raman scattering (SERS) properties of certain molecules embedded in an optical medium can be altered to store information. The SERODS system uses a writing laser, a reading laser, a photometric detector, and an optical disk or a 3-D multilayer optical storage medium. The writing laser encodes bit information by altering the light-emitting properties of specific clusters of molecules on the disk, while leaving other molecules intact. The reading laser excites all the molecules in the disk's optical layer, including specific microregions of the disk, to produce altered and unaltered SERS light signals that correspond with "one" bits and "zero" bits, respectively. The photometric detector tuned to the frequency of the Raman emissions retrieves the stored information.

. . . a high-density optical memory that could hold 18,000 sets of the Encyclopedia Britannica on a single 12-inch optical disk.

TWO COMPANIES, WORLD LIBRARY, INC., AND PHOTRONIX, INC., HAVE ACQUIRED LICENSES FOR SERODS TECHNOLOGY.



■ Dr. Tuan Vo-Dinh of ORNL operates the SERODS optical data storage system, which offers about 100 times greater storage capacity than previous technology.

<sup>1</sup>Marketplace Information Holdings, Inc. 1996. Market analysis report: Computer storage devices. World Wide Web at <http://www.imarketinc.com/anly/reports/rpt3572.htm>.

... porous metal wicks that cool heat-generating Pentium® microprocessors in portable computers.

THERMACORE PRODUCES  
7,000 HEAT  
PIPES PER DAY FOR  
PENTIUM® CHIP-BASED  
PORTABLE COMPUTERS.



■ Thermacore's heat pipes cool today's high-end processors in portable computers without using fans or extremely large or heavy heat sinks.

## HEAT PIPES KEEP CHIPS FROM BLOWING THEIR COOL

Manufacturers of portable computers deal with a hot issue when it comes to chip cooling. To prevent chip damage, heat-pipe technology helps them redirect away the heat that the microprocessor generates. But this technology does not work well when users tip and turn their computers.

Thermacore, Inc. (Lancaster, PA), developed heat pipes that, unlike traditional heat pipes, allow users to tip and turn portable computers without degrading performance. These devices use porous metal wicks, the key to their capabilities. Thermacore developed the heat pipes through SBIR contracts—including several from BMDO—to cool laser mirrors, electronic devices, and batteries.

Thermacore's heat pipes help the Pentium® chip (which has greater cooling requirements because it has over 3 million transistors<sup>1</sup>) find relief from the heat inside portable computers. For example, the company supplies devices to manufacturers for installation in 120- and 133-megahertz Pentium chip-based computers to prevent overheating. Alternative methods of cooling, such as electrically powered fans, are large and have high energy requirements that make them impractical for portable computers. Thermacore's compact, lightweight heat pipes do not interfere with the computer's portability. Also, since they use no electricity, the heat pipes conserve the precious energy essential for battery-powered portables.

To meet market demand, Thermacore enhanced the capabilities of its manufacturing division, Thermal Products. This division now produces 7,000 heat pipes per day (a rate based on existing and expected orders) to cool high-end Pentium-based portable computers. According to Yale Eastman, chairman of DTX, Thermacore's parent company, "In 1997, Thermacore expects to manufacture over 2 million heat pipes for this thermal management application."

Developing prototypes for desktop and workstation computer markets, Thermacore's heat pipe technologies provide the cooling improvement needed for increased computer speeds. "Faster chip speeds and microprocessor-intensive software create higher levels of heat in desktop and workstation computers," adds Eastman. "Our heat pipes are more reliable than other technologies and could provide all the cooling necessary to prevent chip damage."

### ABOUT THE TECHNOLOGY

Thermacore's passive heat pipes use porous metal wicks that move the heat-transfer liquid quickly and efficiently, using capillary action. Like kerosene in lantern wicks, the heat-pipe liquid moves against the force of gravity, making these devices ideal for any cooling need where the system moves. Other heat pipes lose their effectiveness when turned upside down because their wicks will not work against gravity.

Heating one end of the pipe causes evaporation of a liquid inside, absorbing heat. The vapor then flows to the opposite end of the pipe. At this cooler end, it condenses back into a liquid, thereby releasing heat. To repeat the cycle, the wick absorbs the condensed liquid and transports it back to the hot end. Capillary action, the same action that pulls kerosene through the wick in a kerosene lantern, moves the liquid along the wick.

<sup>1</sup>Intel Microprocessor Quick Reference Guide. 1996. World Wide Web at <http://www.intel.com/pressroom/quickref.htm>.



## HOLOGRAPHIC MEMORY SPEEDS ACCESS

Today's specialized computer applications demand extraordinary data storage capacity and quick access. Despite the recent capacity and performance improvements of magnetic and optical disks, these emerging applications still require more—a fundamentally different approach that combines a quantum increase in storage with faster access. Holography provides such an approach.

Aided by a BMDO SBIR contract, Holoplex, Inc. (Pasadena, CA), has developed a holographic memory system that combines quick access with dense storage. The system, dubbed HM-100, can store up to 1,000 gray-level images, each with 1,000 × 1,000 8-bit pixels, for a total of 1 gigabyte of storage. The HM-100 has a very fast internal image processing rate, so that many images can be compared quickly. The entire database of 1,000 images can be scanned in one second.

Applying the data storage technology for security applications, Holoplex recently delivered its first HM-100 to Hamamatsu K.K. in Japan for real-time fingerprint identification. This system functions as a holographic "lock" that can store up to 1,000 fingerprints as holograms. To gain entry to a room, one places a finger on a glass plate. The fingerprint must match one of the holograms in the system's memory. The fast memory of the HM-100 minimizes the delay while the system searches for a match.

In addition to fingerprint identification, the HM-100 offers a compact and low-cost alternative to the large, expensive CD-ROM "jukeboxes" that now store data for hospitals, libraries, and banks. Holoplex's system could save businesses both time and money, replacing their systems with a single 3-D holographic disk. Other uses for this technology include archival storage, government systems, military intelligence networks, and the ever-popular video game. Holoplex aims to capture a significant portion of the holography market, which it estimates at \$20 billion worldwide.

On a futuristic note, Holoplex's holographic memory may someday steer vehicles. One of the company's founders, Demetri Psaltis, used the holographic memory to drive a small car through the corridors of the California Institute of Technology. Psaltis is now designing a different vehicle with enough memory to travel around the campus.

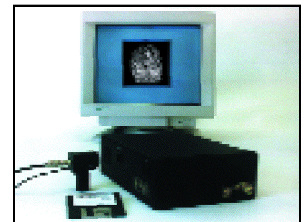
### ABOUT THE TECHNOLOGY

The HM-100 module writes once, but reads many times and holds information in the form of 3-D holograms. Viewing the cube from various angles with the probe laser allows access to the image data stored as 2-D pages. The memory of the HM-100 module includes a temperature-controlled laser diode operating at 680 nanometers, a prerecorded holographic medium (a DuPont photopolymer) mounted on a motor, a two-beam steering mirror, and a tracking mechanism.

The data are converted into a pattern of clear and opaque squares on a liquid crystal display screen, then imprinted on the device. Then, lenses focus a blue-green laser beam shining through this crossword-puzzle-like pattern, or page, to create a signal beam. Next, a second beam, the reference beam, meets the signal beam, creating a hologram of the page of data in a photosensitive medium. Illuminating the hologram with the reference beam used to record it retrieves any stored page. Charge-coupled devices, which produce a current in response to light, read the reconstructed page.

. . . a holographic memory system that combines quick access speed with dense storage.

HOLOPLEX AIMS TO CAPTURE A SIGNIFICANT PORTION OF THE HOLOGRAPHY MARKET, ESTIMATED AT \$20 BILLION WORLDWIDE



■ Holoplex's HM-100 module, pictured above, is being used by one company as a holographic "lock" to store up to 1,000 fingerprints as holograms.

... a hybrid computer that will learn ten times faster than conventional neural networks.

WORKING WITH  
LOCKHEED MARTIN, IAI  
IS USING FUZZY CMAC  
TECHNOLOGY TO DEVELOP  
A SYSTEM THAT CANCELS  
MACHINE VIBRATIONS.



■ RotoScan™, pictured above, is a ballistics testing device whose automation may be enhanced with IAI's Fuzzy CMAC technology.

## HYBRID COMPUTER TO SIMPLIFY CONTROL SYSTEM DESIGN

Design difficulties limit the use of neural networks for real-time control. For example, designers require complex models to account for many system variables. Furthermore, these variables change constantly, testing the neural network's limited ability to adapt to changing conditions.

To solve this problem, Intelligent Automation, Inc. (IAI; Rockville, MD), is developing the Fuzzy Cerebellar Model Arithmetic Computer (CMAC) with funding from BMDO's SBIR program. IAI's technology will learn ten times faster than conventional neural networks. It could simplify the design of real-time control systems and improve the speed and precision of pattern recognition systems.

Using its Fuzzy CMAC technology, IAI is working with Lockheed Martin to build a system that cancels machine vibrations, enabling machine tools to cut faster and more accurately. It is also developing a scanning-probe microscope that learns the characteristics of the sample as its scans, allowing faster and more accurate images. In a test, Fuzzy CMAC detected abnormal traffic patterns on a highway with 99 percent accuracy. Fuzzy CMAC has also tested successfully as a nonlinear adaptive signal filter.

Applying its innovative technology to law enforcement, IAI will use Fuzzy CMAC to further automate RotoScan™, a patented device for analyzing scratches (or striations) on a bullet, also known as ballistics testing. Useful as evidence in court, these scratches are the "fingerprint" of a particular gun on a spent bullet. A computer stores the bullet images on a disk, enabling investigators to identify and match the bullets. IAI and Mnemonic Systems, Inc., experts in forensic technology, are currently building RotoScan devices for law enforcement agencies.

Another potential application for Fuzzy CMAC is in flight control systems. For example, the ability to predict maneuverability and to accommodate uncertainties makes flight control systems more reliable and adaptive. When pilots input certain control parameters, they expect the aircraft to respond accordingly. But a full or near-empty gas tank may cause the response to differ from their expectations. IAI's technology could adjust for this difference in real time. In another application, Fuzzy CMAC could help weapons systems lock on to targets quickly and accurately.

### ABOUT THE TECHNOLOGY

Fuzzy CMAC combines the ease of coding and the flexibility of fuzzy logic controllers with the self-learning ability of neural networks. These technologies enable the system to learn and to generate output faster than other learning control mechanisms. IAI expects Fuzzy CMAC to be easier to install in system hardware than conventional neural networks. For example, one test verified the possibility of easy and affordable customization of the device as a multiple-digital signal processor for an active-vibration isolation system, executing operations at close to a gigaflop rate.

## NETWORK SOFTWARE PROTECTS AGAINST CYBERTHREAT

Information security is an increasingly important issue for both private companies and the Federal Government. Information thieves are hacking into more company networks, stealing, modifying, or destroying confidential data. Some, interested only in causing chaos, shut down or crash entire computer systems and networks, costing companies thousands of dollars to assess and repair the damages. Also, Internet access allows an increased number of attacks on the U.S. military; it has been estimated that as many as 250,000 hacker attacks occur on the U.S. Department of Defense each year.<sup>1</sup>

In an important step toward helping nondefense companies protect their computerized assets, Gemini Computers, Inc. (Carmel, CA), adapted its BMDO-funded information security technology to an electronic bank loan pilot project at the Small Business Administration (SBA) Service Center in Fresno, California. BMDO's Science and Technology office and the SBA jointly sponsored this defense conversion.

Gemini's software, based on a network-level product, features integrated encryption and Department of Defense certification at its highest security level. In the SBA pilot project, this technology protects sensitive information for electronic bank loan operations among three SBA offices: SBA Headquarters in Washington, D.C.; the SBA Operation Finance Center in Denver, Colorado; and the SBA District Office and Service Center in Fresno, California.

The Gemini trusted network processor (GTNP) provides high-level security that helps protect information from such outside threats as computer hackers. It also controls damage from often-overlooked internal threats, such as hostile insiders and computer viruses. Providing companies with this security requires affordable products that minimally affect the performance of the existing network.

Bringing the mandatory security controls of the military to commercial systems, Gemini could contribute to emerging markets such as secure electronic commerce, health care information systems, teleconferencing, and protection of industrial trade secrets. Increased security not only prevents companies from losing valuable information to competitors, but for such areas as electronic commerce and health care information systems, it increases the trust of customers.

### ABOUT THE TECHNOLOGY

The GTNP provides multilevel security, encryption, and concurrent processing. Gemini designed the GTNP to support integration with other technologies and products in order to build a variety of secure network interconnections and secure data-sharing components for multilevel, secure distributed information systems. GTNP's open architecture does not restrict its use to a single application or suite of protocols. Instead, applications and protocols can be developed to run on top of the GTNP-structured computing base to support the specific network requirements. The Gemini Multiprocessing Secure Operating System Security Kernel runs the GTNP. This software implements real-time, priority-based scheduling to provide multiprogramming and multiprocessing to support concurrent computing, including parallel and pipeline processing.

. . . software that can protect a company's computer networks against hackers and hostile insiders.

GEMINI'S TECHNOLOGY  
COULD CONTRIBUTE TO  
EMERGING MARKETS SUCH  
AS SECURE ELECTRONIC  
COMMERCE AND HEALTH  
CARE INFORMATION SYSTEMS.



■ Pictured above is a defense installation whose networks can be secured against cyberthreats using Gemini's technology. Nondefense networks can also be protected.

<sup>1</sup>United States Government Accounting Office. 1996. Information security: Computer attacks at Department of Defense pose increasing risks. No. GAO/AIMD-96-84, 22 May. GAO Reports and Testimony: May 1996. Washington, DC.